Analysis of Microwave Propagation in Plasma

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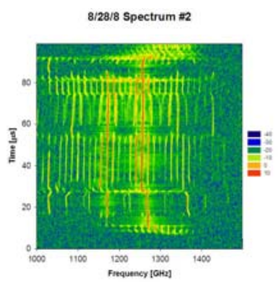
Introduction

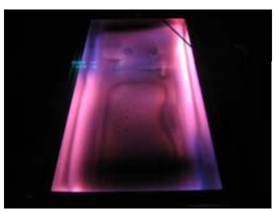
- Plasma can be controlled electronically and supports the propagation of high-powered electromagnetic waves
  - Useful feedback mechanism in a backwards wave oscillator (BWO)
  - Modulate dynamics of the system using plasma
  - High-powered BWOs can demonstrate multi-frequency operation



- Other applications:
  - beam steering using plasma
  - focusing high powered waves at a distance
  - propagating microwaves in space
- Must first study how microwaves propagate through plasma

Theory

- Plasma – formed by collisional excitation of gas in an electric field



- Calculating plasma density, the free electrons per volume of a plasma, using the Hall potential

$$n_e = \frac{B_z I_{plasma}}{qE_{Hall} A}$$

- Plasma frequency

$$\omega_p = \sqrt{\frac{n_e e^2}{\varepsilon_0 m}}$$

  - rate at which electrons in plasma oscillate around their equilibrium positions
  - affects the permittivity of electromagnetic waves
- Plasma permittivity

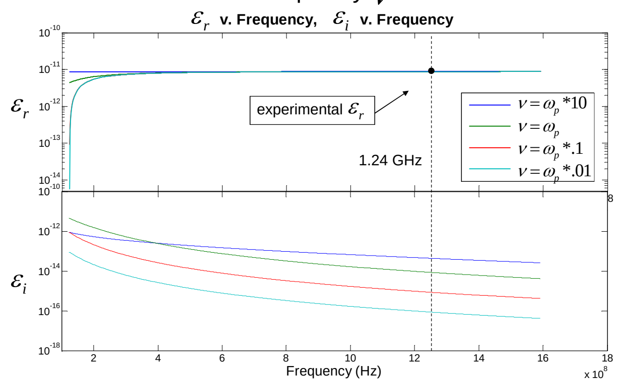
$$\varepsilon = \varepsilon_0[(1-\frac{\omega_p^2}{\omega^2+\nu^2}) + i\frac{\nu\omega_p^2}{\omega(\omega^2+\nu^2)}]$$

Theory

- Wave number

$$k = \omega\sqrt{\mu_0\varepsilon} = \omega\sqrt{\mu_0\varepsilon_0(1-\frac{\omega_p^2}{\omega^2+\nu^2})} \qquad k = k_0 + \Delta k = \frac{\omega}{c} + \frac{\Delta\phi}{2L}$$

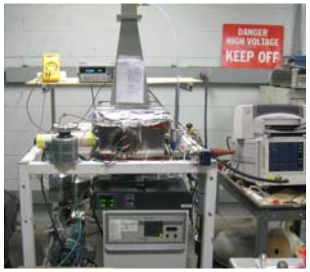
- The effect of collision frequency ν:



- At 1.24 Ghz: ε_r is not affected much by ν
- ε (and thus k) is insensitive to collision frequency
- $\varepsilon_r >> \varepsilon_i$ above 400 MHz, so low loss above this frequency

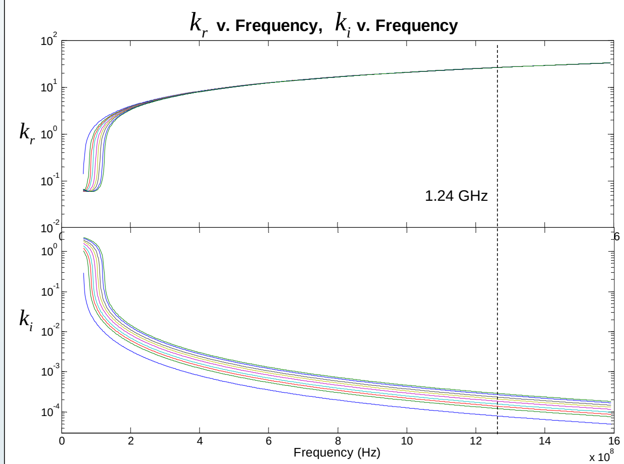
Experiment

- Generating the low pressure plasma
  - Pump down the pressure in the tanks using the mechanical and turbomolecular pumps
  - Bleed in air until the pressure reads 10 mTorr
  - Use a high voltage power supply to create an electric field between two electrodes in the tank
  - The free electrons collide with neutral gas molecules, freeing more electrons
  - Continues until ionization rate equals the recombination rate
- Measurements taken (at pressure 10 mTorr, phase shift from 1.24 GHz):
  - Plasma potential
  - Hall potential
  - Plasma current
  - Phase shift



Data Analysis

- Used ν=1.8E7, obtained from a study with similar plasma conditions



Conclusion

- Electromagnetic wave propagation in an atmospheric low density plasma has been investigated in the regime where $\omega > \omega_p$
- Above 400 MHz, $k_r >> k_i$ was demonstrated, therefore electromagnetic wave propagation is low loss
- Using a simple electronic means of controlling plasma excitation, able to adjust k_r from 25.824 to 25.843

Discussion

- Can use the results for applications where you need to know the dispersion of microwaves in plasma
  - Ex: selecting a region of operation in the BWO
- Future work
  - analyze the propagation of electromagnetic waves close to plasma frequency